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RELATIVE SUSCEPTIBILITY OF PONDEROSA PINES TO BARK-BEETLE ATTACK

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Recent heavy killing of ponderosa pine in the Pacific States through attacks of various bark boring beetles, principally the western pine beetle (Dendroctonus brevicomis Lec.), has brought to the forefront the important question of controlling or eliminating such losses. In the mature and overmature ponderosa pine stands of California, Oregon, Washington and Idaho during the past two decades, these beetles, collectively referred to as "pine beetles", have caused an annual timber loss which has run into billions of board feet. Some areas have lost such high percentages of merchantable stands as to become valueless for logging. Over many areas, the annual mortality has so greatly exceeded growth as to result in a serious depletion of mature timber reserves. Such losses as these raise a serious question as to the feasibility of profitable sustained-yield timber production in the pine region, and discourage private timber operators from leaving any merchantable volume in the woods, if it can be profitably liquidated at the time of logging.

Both from the immediate viewpoint of timber salvage, and the forestry objective of a satisfactory silvicultural management of ponderosa pine stands, one of the first requirements in the solution of

the pine beetle problem is a knowledge of what type of tree represents the greatest risk of beetle attack. Once the type of tree most likely to be killed can be recognized with a fair degree of certainty, then it is possible to make partial cuttings of beetle susceptible trees, either for the purpose of salvaging valuable high-risk trees before they are damaged by beetle attack, or for the silvicultural objective of reducing mortality and increasing net growth.

During the past decade, the relative susceptibility of different types of ponderosa pine to pine beetle attack has received considerable study by silviculturists and forest entomologists. These studies have revealed that for trees of certain types, the risk of being killed by beetles is distinctly greater than it is for other trees in the same stand. In general, the trees more susceptible to attack are the weaker, less vigorous individuals, and to a certain degree, those more advanced in age. The problem then, is one of recognizing the combination of characters which indicate susceptibility.

Dunning[1], in the study upon which he based his tree classification, found that in terms of basal area, the probable insect loss was greatest for his classes 7, 5, and 4; and that in terms of number of trees, it was greatest for classes 4, 2, 5, and 7, in that order. Person[2] reached similar conclusions and found that the beetles showed a decided preference for slow-growing trees, for trees in the diameter range between 20 and 30 inches, and for those growing on the poorer sites. This selection, he found, was less marked under decreasing epidemic conditions than under endemic or increasing epidemic conditions. Further extensive studies made by the writer from 1927 to

1932, in connection with western pine beetle surveys in southern Oregon and northern California, repeatedly showed the same selective tendencies. A preliminary summary of these studies has been reported by Meyer[3/].

During the course of these field studies, it became evident that marked differences in susceptibility existed within some of the Dunning tree classes. It even appeared probable that, in some cases, these differences might be greater for certain types of trees within a single class than for different tree classes. In order to isolate the specific characters that were most important in indicating susceptibility, it seemed desirable, therefore, to set up a more detailed classification, with a large number of small, homogenous, easily recognized tree types, which could be used in the field for further study.

DESCRIPTION OF THE BARK-BEETLE SUSCEPTIBILITY CLASSIFICATION

The tree classification, which was adopted for this purpose, and may be called the "bark-beetle susceptibility classification", is illustrated in the accompanying chart. It is based to a large extent upon the same considerations of age, dominance, and vigor which Dunning recognized as forming the basis for his seven classes. The new classification uses these same basic factors to regroup all ponderosa pines into a larger number of classes. The two factors of old age and vigor are given primary importance. Four age groups are recognized, designated 1 to 4; and four degrees of

crown vigor, designated A to D. Combining these two major factors gives a series of 16 classes, covering all types of trees found in a stand.

The tree class descriptions to a large extent follow those defined by Dunning, but have been modified to apply more specifically to the mature ponderosa pine forests of average Site IV quality in southeastern Oregon and northeastern California. While trees throughout the pine region may be similarly grouped into sixteen age and vigor classes, the class descriptions will have to be somewhat modified to apply in other localities and on poorer or better sites.

Age Groups

Trees are first divided into four age groups - young, immature, mature and overmature. In average site IV ponderosa pine stands of the Pacific region, the characteristics of these age groups are as follows:

1. YOUNG. Age: Usually less than 75 years. DBH: Rarely over 20 inches. Bark: Dark gray-brown to black, deeply furrowed, with narrow ridges between the fissures. Tops: Usually pointed, with distinct nodes. Branches: Upturned and in whorls.

2. IMMATURE. Age: Approximately 75 to 150 years. DBH: Rarely over 30 inches. Bark: Dark reddish-brown, with narrow, smooth plates between the fissures. Tops: Usually pointed, but with nodes indistinct. Branches: Mostly upturned and in whorls for upper half of crown.

3. MATURE. Age: Approximately 150 to 300 years. DBH: Rarely over 40 inches. Bark: Light reddish-brown with moderately large plates between the fissures. Tops: Pyramidal or rounded. Branches: Upturned near top, those of middle crown horisontal, lower ones drooping; whorls incomplete.

4. OVERMATURE. Age: More than 300 years. DBH: Usually of large diameter. Bark: Light yellow, the plates usually very wide, long and smooth. Tops: Usually flat and making no further height growth. Branches: Mostly drooping, gnarled or crooked.

In dividing trees into these four general age classes, more weight should be given to relative maturity, or what might be called "physiological age" than to exact age as indicated by annual rings. Some trees growing under favorable conditions, particularly on good sites, retain their youthful appearance and vigor much longer than do trees that have been forced to struggle against unfavorable environmental conditions, such as those on poor sites. Since trees must be judged largely on the basis of external appearances, those having all the outward characteristics of a given age group should be classed in that group, even though they are actually somewhat younger or older than the designated age limits.

The distinction between Classes 1 and 2 is based largely on color and roughness of bark. While both are sometimes called "bull pines" or "blackjacks", only the Class 1 trees have the rough black

bark which is so typical of juvenile growth. The change from Class 1 to 2 takes place at approximately 75 years of age in the site IV stands of southern Oregon. At that age, there is a slowing down in the rate of height and diameter growth, narrow plates appear between bark fissures, and the bark starts to take on the reddish-brown color characteristic of maturity. Suppression in the seedling stage may greatly extend the period of juvenile growth and advance subsequent age limits. The distinction between mature and overmature trees, Classes 3 and 4, is more difficult to recognize and involves character of crown as well as bark differences.

Vigor Groups

In judging the relative vigor of different trees of a given age, the size of crown and abundance of foliage is probably the best outward indicator. Therefore, each age class is further subdivided into four sub-groups based upon relative crown vigor. These are designated by letters A to D as follows:

A. Full vigorous crowns with a length of 55 percent or more of the total height, and of average width or wider; foliage usually dense; position of tree isolated or dominant (rarely codominant); diameters large for age.

B. Fair to moderately vigorous crowns with average width or narrower, and length less than 55 percent of the total height; either short wide crowns or long narrow ones, but neither sparse nor ragged; position, usually codominant but sometimes isolated or dominant; diameters above

average for age.

C. Fair to poor crowns, very narrow and sparse or represented only by a tuft of foliage at the top; foliage usually short and thin; position usually intermediate, sometimes codominant, rarely isolated; diameters below average for age.

D. Crowns of very poor vigor; foliage sparse and scattered or only partially developed; position suppressed or intermediate; diameters decidedly subnormal considering age.

By combining the four age groups with the four sub-groups of crown vigor, a total of sixteen classes was obtained which could be analyzed for relative susceptibility.

According to definition, the comparison between the expanded classification and Dunning's classification is as follows:

Classes Defined by Dunning	Bark Beetle Susceptibility Classes
1	1A, 2A
2	1B, 2B
3	3A
4	3B, 3C
5	4A, 4B, 4C
6	1C, 2C, 1D, 2D
7	3D, 4D

Or in reverse order:

Bark Beetle Susceptibility Classes		Dunning's Classes
Age Group	Vigor Group	
1	A, B, C, D	1, 2, 6, 6
2	A, B, C, D	1, 2, 6, 6
3	A, B, C, D	3, 4, 4, 7
4	A, B, C, D	5, 5, 5, 7

RELATIVE SUSCEPTIBILITY OF THE TREE CLASSES

In order to determine which of these tree classes were particularly favored by the beetles in making their attacks, a study was started in 1928 in connection with western pine beetle surveys in virgin ponderosa pine stands of southern Oregon and northern California. During a four-year period, 1928, to 1931, a total of 27,465 beetle-killed trees on approximately 15,000 acres of sample plots were classified under the bark-beetle susceptibility classification. During the same period, a mechanically selected sample of 22,428 living trees was similarly classified for comparison. In 1932, a 10 percent cruise of the plots was made and the total number of surviving trees was determined, to which was added the number of trees killed by beetles during the previous four-year period in order to reconstruct the original stand as of 1928.

The apportionment of the beetle-killed trees between the different tree classes as compared with the distribution of these classes in the original stand is shown in Table I. The mortality ratio, which has been obtained by dividing the percent occurrence of beetle losses in a given class by the percent occurrence of that class in the original stand, gives a measure or relative susceptibility. If, for instance, 9 percent of the killed trees are found in a certain class, and 9 percent of the original stand is also found in that class, the ratio will be 1.00 which indicates no particular preference. Ratios above 1 indicate that such types are more frequently found among the killed trees and are susceptible, while ratios below 1 indicate corresponding resistance.

TABLE I

Relative Bark-Beetle Susceptibility
of
Virgin Ponderosa Pines in the Klamath Region
Southern Oregon - Northern California

Tree Class		Total Stand[1] Per 1,000 Acres Trees	Percent	Trees Killed in 4 Years[2] Per 1,000 Acres Trees	Percent	Average Percent Trees Killed Per Year	Mortality Ratio	Relative Susceptibility
1	(A	1,983	8.8	24	1.5	.3	.17	16
	(B	1,160	5.1	40	2.5	.9	.49	12
	(C	548	2.4	62	3.8	2.8	1.58	5
	(D	51	.2	8	.5	3.9	2.50	1
2	(A	1,987	8.8	45	2.8	.5	.32	15
	(B	2,181	9.7	153	9.5	1.7	.98	11
	(C	1,409	6.3	229	14.1	4.1	2.24	2
	(D	344	1.5	29	1.8	2.1	1.20	8
3	(A	1,940	8.6	56	3.5	.7	.41	14
	(B	2,387	10.6	189	11.7	2.0	1.10	10
	(C	1,840	8.2	212	13.1	2.9	1.60	4
	(D	674	3.0	65	4.0	2.4	1.33	6
4	(A	1,997	8.9	70	4.3	.9	.48	13
	(B	2,242	10.0	188	11.6	2.1	1.16	9
	(C	1,290	5.7	200	12.4	3.9	2.18	3
	(D	489	2.2	47	2.9	2.4	1.32	7
Total		22,522	100.0%	1,617	100.0%	1.8%	1.00	

[1] Total living pine stand as of 1928, based on a 10 percent cruise of 15,000 acres of sample plots.

[2] Based on 100 percent cruise of beetle mortality on the same sample plots during the 4-year period 1928-1931.

The results given in Table I represent the composite, or average condition found in the region sampled during the period of this study. The stands sampled were all virgin ponderosa pine ranging from site III to site V with volumes of from 6 to 22 M. board feet per acre. Pine beetle infestation varied during the four year period from a highly epidemic condition, with a loss in one year on one 640-acre plot of 880 board feet per acre, to a low endemic kill on another plot of 70 board feet per acre. The average loss on all plots during the four year period was approximately 300 board feet per acre per year.

The mortality ratios represent the general averages found under all of the above conditions. They should not be considered as fixed constants, but rather a sliding scale of values which vary for different stands and intensities of infestation. While the present ratios are undoubtedly significant of the general trend in virgin ponderosa pine stands of this region, quite different ratios may be expected in reserve stands left after different degrees of cutting and in forests placed under management.

On the other hand, the relative susceptibility rank of the different tree classes does not change appreciably under varying conditions. When infestation is low, the selective tendencies are more pronounced and a greater proportion of loss occurs in the more susceptible tree classes at the top of the scale. As the mortality rate increases, more tree classes are included. Under severe epidemic conditions, especially on the poorer sites, nearly all classes of trees, except the

most resistant types, are apt to sustain a nearly equal proportion of the total loss.

It will be noted that in each age group, susceptibility increases with a decrease in crown vigor (A to D), except that in the three older age groups the C crowns appear to be more susceptible than the D crowns. While the number of cases represented by the D crowns may not be sufficiently large to substantiate this point, it has been observed in the field that the very poorest trees, as represented by the D crowns, are often ignored by the beetles while neighboring trees of better vigor are taken. It may be that trees of this class offer too little nourishment to the beetles to make them attractive.

A comparison of the relative susceptibility by comparable crown classes for the four age groups brings out the point that there is a gradual increase in risk with advancing age (1 to 4). It will be noted, however, that the difference in age between one class and the next is not nearly as important in determining susceptibility as a difference in crown vigor class. For instance, an old overmature tree of Class 4A, while more susceptible than younger trees with A crowns, is not nearly as likely to be killed as an immature tree of Class 2B or 2C. Such a veteran dominant tree usually has crowded out all of the trees around it and is well able to continue resisting the elements and insect attacks for a few more years as it has done for the past three centuries or more. A young intermediate or codominant tree struggling for its place in the stand is much more likely to succumb, within the same period of time.

The present study shows that in the ponderosa pine stands of this region, bark beetles are carrying on a natural selection which thins the stands of the weaker individuals and favors the survival of the dominants. They are Nature's silvicultural agents which relieve the pressure of severe tree competition or of critical growth conditions and tend to preserve a natural balance between growing stock and available supplies of plant food and soil moisture. Since all trees with C and D crowns are susceptible to pine beetle attack, with B crowns intermediate and with A crowns resistant, it is apparent that these beetles are effecting a type of tree elimination which is comparable to an improvement thinning. Year by year they are making "thinnings from below" and a "selection cutting" of the older age classes. On poor sites this elimination during epidemic periods sometimes approaches a clear cutting. This thinning process is largely responsible for the spacing found in a natural forest. The beetles show a marked tendency to concentrate their attacks upon trees growing in groups - probably because of the severe competition which group-wise trees may experience, especially during periods of drought.

APPLICATION TO MARKING PRACTICE

To illustrate how the results of this study may be of value in connection with marking virgin ponderosa pine stands for salvage or selection cuttings, it may be of interest to examine the following table (Table II) in which the average stand structure on 15,000 acres

of site quality IV ponderosa pine in southern Oregon is used as a basis. In this table the merchantable stand is subdivided into groups according to relative susceptibility and value.

For practical purposes, the 16 tree classes are arranged in three general susceptibility groups as follows:

Susceptible types - This group includes all trees with C and D crowns and according to relative risk from higher to lower, the tree classes belonging here appear in the following order: 1D, 2C, 4C, 3C, 1C, 3D, 4D, 2D.

Intermediate types - This group takes in trees with B crowns in the three older age classes. From higher to lower risk in this group, the order is as follows: 4B, 3B, 2B.

Resistant types - This group, on the average, is resistant to beetle attack and therefore comprises the best trees to leave in the reserve stand as far as pine beetle risk is concerned. From the poorest risk to the best, these classes are as follows: 1B, 4A, 3A, 2A, 1A. All except class 4A are types of trees which are normally left under present Forest Service marking policy.

In the following table, trees 10 inches or more in diameter are arranged by classes according to these three susceptibility groups and further according to their relative commercial value as indicated in a study by Anderson[4] for comparable tree classes.

TABLE II

GENERAL SUSCEPTIBILITY AND VALUE GROUPING OF VIRGIN PONDEROSA PINE STAND ON SAMPLE AREA OF 15,000 ACRES IN SOUTHERN OREGON

Susceptible types. Trees of highest beetle risk.

Tree Class	Average Diameter (Inches)	Average Volume (Bd. Feet)	Percent of Stand By Volume (%)	Percent Totals (%)
Trees usually of high value				
4C	28	1,280	9.1	
3C	21	540	5.3	
Total in this group				14.4
Trees usually of low value				
2C	16	160	1.1	
4D	18	300	1.0	
3D	14	140	.5	
2D	12	70	.1	
Total in this group				2.7
Unmerchantable				
1C	12	60	.2	
1D	10	30	--	
Total in this group				.2
Total in this type				17.3

Intermediate types. Trees of fair risk under average conditions.

Trees usually of high value				
4B	32	1,790	23.0	
3B	26	930	12.4	
Total in this group				35.4
Trees usually of low value				
2B	19	300	3.7	
Total in this group				3.7
Total in this type				39.1

Resistant types. Trees representing good risks.

Trees usually of high value				
4A	35	2,200	25.5	
3A	27	1,100	11.9	
Total in this group				37.4
Trees usually of low value				
1B	14	100	.7	
2A	20	370	4.3	
1A	14	100	1.2	
Total in this group				6.2
Total in this type				43.6
Total				100.0

If the primary purpose of a marking is to salvage valuable trees which are apt to be killed before they are reached in the normal course of logging, then only such classes of beetle susceptible trees as will yield a profit need be included. Trees of zero value may be left in the woods to run the risk of beetle attack, for even if they are killed no present convertible value has been lost. On average sites or better, Classes 4C and 3C, which in the stand illustrated in Table II contain 14.4 percent of the volume, would be given first consideration. A few of the other C and D crown trees might be taken when accessible. If the site were poorer than average, then trees of Classes 4B and 3B, representing an additional 35.4 percent of the stand in trees of intermediate risk but of high value, should be included.

Such a plan of salvage would necessitate covering large areas with a light cut in a short space of time. Economic considerations will decide to what extent such a plan is feasible and how large a volume will have to be removed to make the operation profitable. Unless the cut is heavy enough to open up the stand and stimulate growth in the reserve, the effect in reducing the threat of beetle infestations is apt to be negligible.

If, on the other hand, the primary purpose of a marking is to forestall pine beetle outbreaks and reduce mortality rates, then all the more susceptible types of trees likely to foster infestations should be removed and the stands sufficiently thinned as to give noticeable release and growth stimulation to the reserve. This usually

will involve a much heavier cut, and it will not be possible to cover an area as quickly as with a salvage cutting. In average site IV stands, the minimum requirement would be the removal of the more susceptible types, which include all Class C and D trees. On poorer than average sites, trees of intermediate risk, the older trees with B crowns, would also need to be taken.

While it seems reasonable to suppose that a stand which has been thinned of the more susceptible trees should be in better shape to resist bark beetle epidemics, there is no proof as yet that such stands will be immune to further losses. During periods of bark beetle epidemics, trees of all classes may be killed with little regard to apparent vigor. Also, on poor sites, in "fringe type" timber, and on areas suffering from the effects of drought, all types of trees are reduced in vigor and resistance to pine beetle attack, and tend to become nearly equal in susceptibility. There are many examples to show that on such problem areas it is futile to leave as a reserve any but the youngest and most vigorous trees.

It will be noted that the marking suggested for the purpose of preventing beetle outbreaks is comparable to present marking practice in the ponderosa pine forests of the national forests and Indian reservations of this region. Under this more or less standard system, all of the more susceptible and intermediate types of trees (Table II) are marked for cutting, as well as beetle resistant trees of Class 4A. A cutting under this system removes approximately 80 to 85 percent of the

stand and so nearly eliminates all types of beetle susceptible trees on the area cut over that the problem of salvaging additional values or further reducing the threat of beetle loss is usually solved. However, during the last decade, on poor sites and in fringe type timber, the beetle losses to reserve stands cut under this marking practice have been such as to raise considerable doubt as to its adequacy under these circumstances.

Cutting all merchantable timber, such as is the practice on many private operations, of course eliminates for a good many years further trouble from western pine beetle. Such cuttings, if protected from fire, produce even aged stands, often with satisfactory stocking, but with the prospect of a second timber crop projected far into the future. For certain problem areas, such as those mentioned above, a heavy cut is undoubtedly the only practical solution of eliminating serious beetle losses in reserve stands and of obtaining substantial net annual growth.

Silvicultural management of our ponderosa pine forests should eventually lead to the solution of present pine beetle problems. Improvement of growth conditions and the reduction of mortality are such closely related phases of timber management that the measures necessary to accomplish one are certain to have a beneficial effect upon the other. The types of trees which should be cut in order to improve growth in the residual stand are also those which should be removed in order to reduce mortality. While management may not eliminate all

future bark beetle troubles, it is at least a step in the right direction of improving the chances of ponderosa pine stands to escape such injury.

In actual practice, economic considerations will often dictate the extent to which silvicultural and bark beetle hazard-reduction measures may be applied. Because of low commercial values, it will often not be feasible to remove all of the small beetle-susceptible trees which might be desirable to cut from a strictly entomological standpoint. The final solution of any marking problem will of necessity be determined by weighing the importance of growth, mortality and economic factors, keeping always in mind the ultimate objective of continuous profitable forest production.